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HYDROLOGY IN ZIMBABWE - THE PAST AND THE FUTURE

by

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INTRODUCTION

At the time of independence Zimbabwe was unique among African nations which gained independence before 1980. It was unique in terms of a relatively, and indeed absolute, highly developed infrastructure in industry, agriculture, science and engineering. The author well recalls the post-independence donor-aid rush into Zimbabwe by numerous eminent consulting engineers accompanied by climatologists who brought with them their own raingauges only to find that where they expected cursory and few rainfall records, there existed 90 years of countrywide rainfall data, fully computerised, tabulated, analysed and synthesised. Not only was this the picture in terms of data generally, but also in terms of human expertise; there were many engineers and scientists with 30 years background and experience of the water resources of this country. This background and experience is totally irreplaceable and no expatriate can ever match it. It is thus fair to note that the "state of the art" in water resource development in Zimbabwe was well advanced with over 8 000 dams (110 over $2 \times 10^6 m^3$), 40 000 boreholes and sophisticated research and endeavour in most aspects of hydrology and water resource engineering.

With the advent of independence the accent on water resource development has changed. The new Government's major thrust turned to the rural areas and thus rural water supply development gained in importance. It is in this sector that outside foreign donor aid has played a major and significant role.

While this paper describes the history of hydrology in Zimbabwe it is of course difficult to divorce this from water resources development generally and indeed the author has not attempted to do this.

SURFACE WATER RESOURCES - THE PAST

The earliest reference to hydrology (in the broadest sense) in this country dates back to 1889. A Royal Charter was issued to the British South Africa Company authorizing it to "assign to the natives inhabiting Southern Rhodesia water".

As early as 1914 the essence of the Water Act to protect the interests of the occupants in the Native Reserves read as follows: "Whenever any decision or award of a water court in respect of any application for water or combined irrigation scheme or any other matter is likely, in the opinion of the water court, substantially to affect the requirements for primary use of the inhabitants of Tribal Trust Land, such decision or award shall not take effect unless and until the approval of the Board of Trustees for the Tribal Trust Land has been obtained". However, apart from the BSA Company there was no Government department to oversee the Act or to undertake water flow measurements.

In the early twenties Government formed a Division of Irrigation within which there was designated one hydrographic engineer who was responsible for designing and building flow measurement devices and thus organising runoff data for the country.

The earliest records of runoff are available from 1912 (Cleveland Dam near Harare) and from 1923, the Hillside Dam near Bulawayo, both on granite catchments. Other early runoff records date back to 1918, Mazoe Dam (built by the BSA Company for a large citrus estate), 1926 Umtali River, 1929 Umshigoshi and 1932, Dassure River.

In 1927 the first attempt was made to establish a rainfall/runoff relationship from the records available on Cleveland and Hillside Dams. This was in the form of a table giving the minimum runoff for given seasonal rainfalls on two typical catchments, one in Mashonaland with an average seasonal rainfall of 620 mm and one in Matabeleland with an average seasonal rainfall of 480 mm. This table was included in a bulletin "Small Earthen Storage Dams" and was revised in 1938 when the average runoff figures were included in the table. It has since been found, however, that the runoff figures from Cleveland were in error due to the fact that the assumed discharge from the spillway was too high and high figures of evaporation were taken.

In 1948 Wallis drew up the first isopleth map of useful yields from Southern Rhodesia catchments. This was based mainly on the isohyetal map produced by the Meteorological Department giving a certain amount of bias to the isopleths to allow for the various factors affecting the yield. It further represented the yield from a theoretical dam built in the catchment (i.e. to store the average annual yield).

By the mid-nineteen fifties the Hydrographic Branch was renamed the Hydrological Branch, still within the Division of Irrigation. The building of flow measurement devices continued and the Branch was now much involved in overseeing water rights countrywide and acting as expert witnesses to the Water Court.

The first Hydrological Year Book was produced by the Branch in 1956/57. The book contained data on measuring devices in the country such as total runoff in Ac.ft., unit R/O in Ac.ft/sq. mile, plus max. and min. monthly flow in cubic ft/second. The first year book had 68 pages; the latest year book to be published in 1978/79 has 320 pages!

The Branch was active in the late forties and early fifties in the pre-planning stages for the Kariba Dam, in particular gauging the Zambezi River in flood (a hazardous exercise indeed in those days) so that a first order rating curve was available for the planning of what was then the largest dam in Africa. This work was recognized by the award of the O.B.E. to I.H.R. Shand, the then Chief Hydrological Engineer.

In 1963 W.G. Wannell succeeded Shand; Wannell held this post for 13 years and under his wise council and enthusiastic approach the Branch grew in numbers with a staff of 9 engineers and 9 technicians and 15 ancilliary workers.

Apart from the basic tasks of ever-expanding the flow measuring network the Branch was now engaged in a wide spectrum of hydrological research activities. Hydrological research in Zimbabwe at that time was reinforced by the formation of the Agricultural Research Council of Central Africa which supported a full-time Hydrology Research team and which worked in close co-operation with the Government's Hydrological Branch.

Some of the research projects carried out by the Branch included: continuing rainfall/runoff correlations, the effects of afforestation on streamflow in the eastern districts, application of cetyl alcohol in reducing the effects of evaporation from open water bodies; sedimentation in the major dams including Lake Kariba; the effect of seiches within Lake Kariba and new techinques of streamflow and floodflow measurements by use of nuclear techniques.

The mid-sixties saw some outstanding theoretical work of international standard emanate from the Hydrological Branch primarily by T.B. Mitchell. In 1963 the Government acquired a main frame digital computer. Although primitive by today's standards the facility revolutionised the Hydrological Branch's ability to carry out large scale data processing of hydrological information. Mitchell initiated this work which also performed the matrix operations required for the Markov type reservoir yield analysis.

In what is acknowledged to be a classic paper, Mitchell (1965) outlined a method for estimating long-term permissible yield from Zimbabwean storage works at a given risk level. He developed an expression to represent the storage equation of a reservoir with due allowance for losses through evaporation. He showed that by using this expression together with the annual inflow probability distribution, the solution to the problem by means of simultaneous equations derived from the Markov process is possible. He also showed that an analytical solution was indicated for inflow distribution of the gamma type.

In a later paper Mitchell (1977) developed the equally important concept of "hydrologically similar" catchment areas and devised simple rules for the compilation of the approximate combined yield of two or more dams in a series of river systems. These rules involve the transformation of the variable rates of inflow and drawoff that are found in practice into their constant equivalents which can then be easily analysed with the basic Moran dam model. This concept is now routinely used in the operations of Kyle, Bangala and Manjirenji Dams on the Mutirikwi and Chiredzi Rivers.

The mid-sixties also saw the beginnings of the use of radioactive tracers in hydrology in Zimbabwe. This work was initiated by Sir Charles Pereira then Director of the Agricultural Research Council and was undertaken by the Hydrology Research Team of the Council. Nuclear research in Hydrology encompassed both surface and groundwater hydrology. The emphasis in surface hydrology was the development of a rapid, simple and accurate flow stream gauging method; the dilution method for which the Hydrology Research Team were awarded an International Atomic Energy Agency Research contract. Later work included the use of radioactive tracers in floodflow gauging.

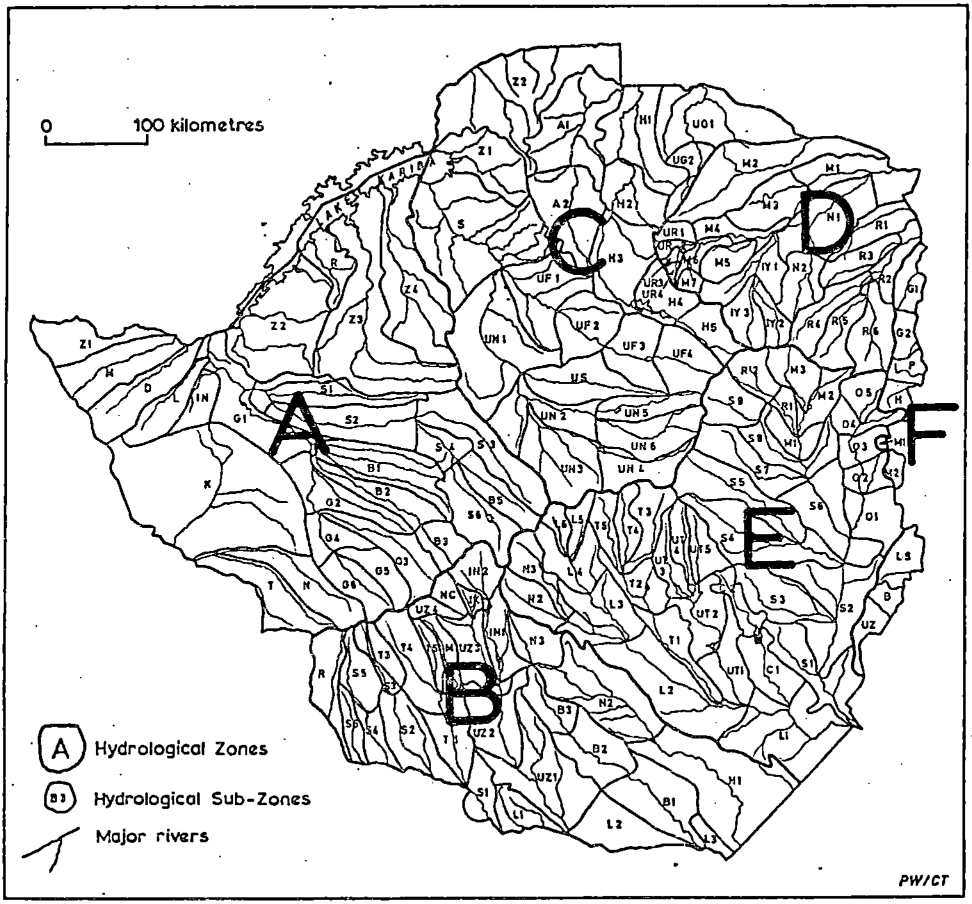
Artificial gamma emitting radio tracers were and are still used to measure streamflows of up to 50 m^3/sec with an accuracy of ±5%. Such gaugings were carried out in selected sites unfavourable for the more orthodox measurement method and where gauging weirs required calibration or confirmation of flow.

The floodflow technique developed by the team and reported at the International Association of Hydrological Sciences, 1982 Exeter Conference utilised artificial tritium; large floods of up to 300 m^3/sec were measured thus extending the rating curves at several catchments and in the case of the Odzi River revealing an error of a factor 2 at high flows.

Pre-eminent in nuclear hydrology in Zimbabwe for many years was Dr P.R.B. Ward. Ward also made the definitive contribution to the understanding of seiches on Lake Kariba. He showed that seiches on Lake Kariba arise primarily during November and are due to winds which blow strongly for several hours from one direction and then reverse and blow strongly from the opposite direction.

As already noted, the first tentative assessment of Zimbabwe surface water runoff was made with the "Isopleth" concept in 1957/8. In 1972 Kabell significantly enhanced the picture of the surface water resources of the country. In a Ministry of Water Development publication Kabell set out to assess how much water can be expected to run off from each Hydrological sub-Zone (Figure 1); how much water should theoretically be impounded and to estimate the limit to the quantity of water that can be made available if the necessary storage is provided. Kabell used Mitchell's

FIGURE 1: HYDROLOGICAL ZONE MAP OF ZIMBABWE



method of dam yield calculation to produce storage/yield relationship curves for risk factors of 4% and 10%. The curves are shown in Figure 2 and can be used both for assessment of potential catchment yields and for preliminary estimates of the yields of specific storage works. As so correctly noted by Kabell, an essential prerequisite for the forward planning of water resource development is an overall assessment of the water potential in each catchment of the country. In 1984 Kabell published a new assessment of the surface water resources of Zimbabwe. This paper was a vital contribution to national development planning. The 1982 assessment takes account of revised estimates of catchment runoff parameters, refinements in the system of yield calculation, and a compilation of all existing storage and water use in each of the hydrological sub-zones. Kabell used new analytical approaches and the figures as shown (Figures 2, 3, 4, 5) provide a sophisticated "state of the art" assessment of the surface water resources of Zimbabwe.

The floods of Zimbabwe have also been studied in the past 20 years. Papers by Roberts (1934), Kabell (1962), Grant (1973) and Ahrenovitz (1974) analysed the major floods in an attempt to produce formulae for the estimation of annual floods. The currently accepted formula for the mean annual flood in Zimbabwe's rivers is that by Mitchell (1974) who analysed flood data up to 1972. Mitchell examined extreme peak floods and proposed a maximum flood formula for Zimbabwe conditions as follows:-

$$\text{Log }(MPF + 1) = 1.175\,(\log (A + 1))^{0.755} + 3.133$$

where MPF = 10 000 year flood : m^3s^{-1}

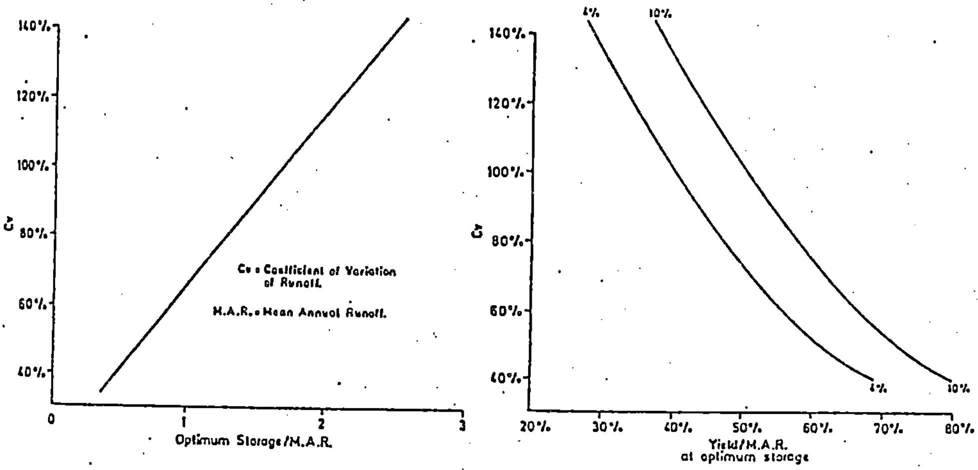
A = area : km^2

In his paper Mitchell also presented reduction factors for annual floods at shorter return period.

A further significant contribution made by Kabell (1974) is his assessment of Design Flood hydrographs. The paper presents a generalised method of assessing the time to peak, and thus the shape of the design flood inflow hydrographs. It also presents for the first time in Zimbabwe, recommendations for selecting the appropriate return period of the design flood based on hazard rating and size of dams.

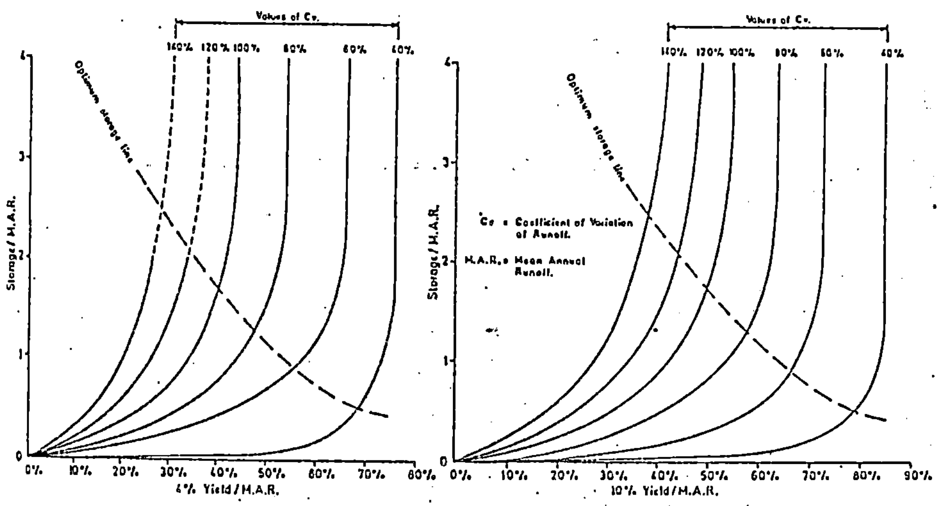
A.F. Frere wrote an important paper in 1974 on the Design Capacity of gauging weirs. The accuracy of flow measurement with standard notch-plates and flumes is about ±5%, compared with ±20% for other gauging methods such as broad-crested weirs, control sections (rated by uniform flow formula or current meters) and notches operating outside their design limits due to drowning, siltation or poor flow conditions. In this context the Design Capacity of a

FIGURE 2: STORAGE YIELD RELATIONSHIPS



NOTE: Yield at optimum storage is approximately 90% of maximum possible catchment yield.

FIGURE 3: Cv-OPTIMUM STORAGE-YIELD RELATIONSHIPS



NOTES

1 Curves are based on Mitchell's method of yield calculation using k=0,8., r=FCv., constant rate of draw-off.
2 These curves represent generalised conditions and are not necessarily accurate for any specific storage works.
3 In particular, the optimum storage line may not indicate the economic optimum storage capacity which will be primarily dependent on site topography.

FIGURE 4: UNIT POTENTIAL YIELD

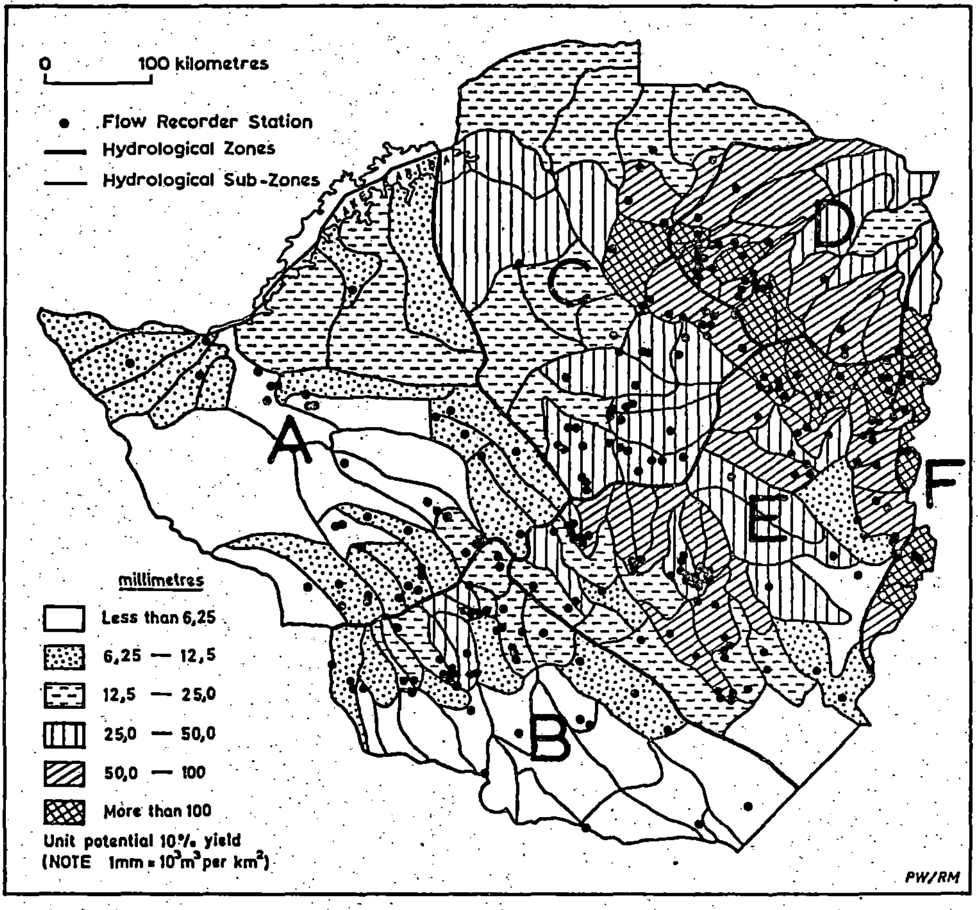
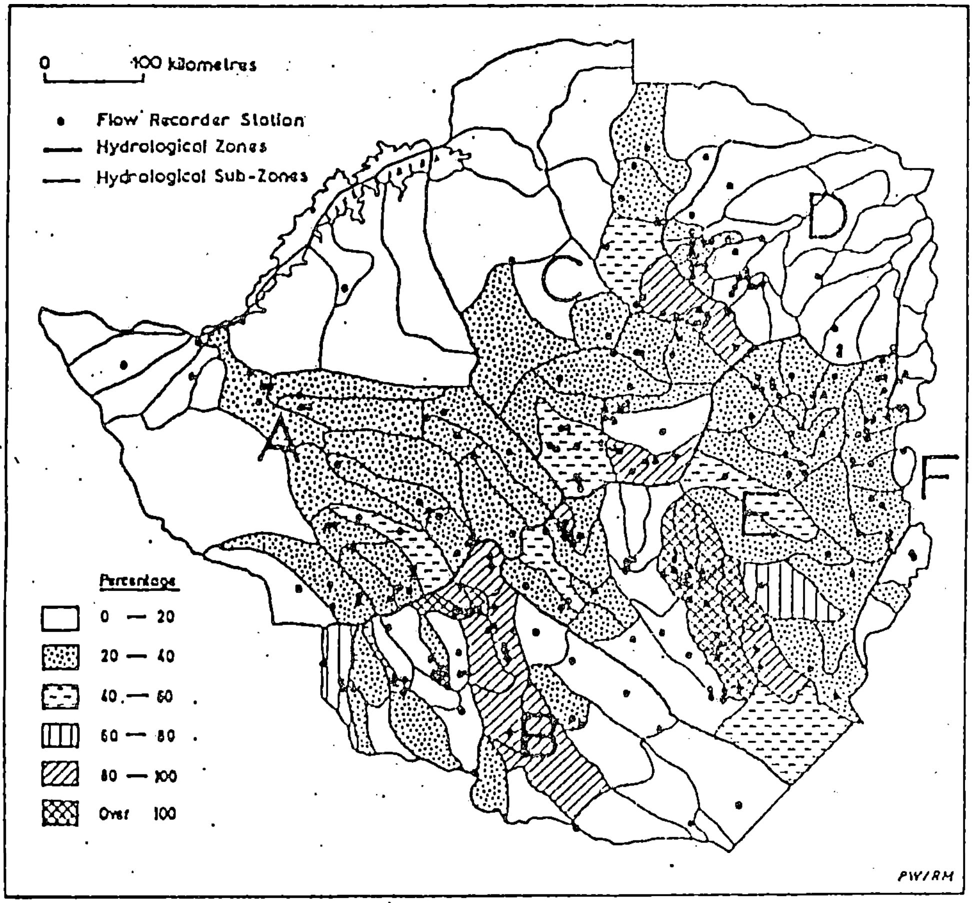


FIGURE 5: CUMULATIVE PERCENTAGE UTILISATION



gauging weir is defined as the maximum flow that can be measured with an accuracy of ±5%.

Frere argued that the aim of adopting a standard for the Design Capacity of a gauging weir would achieve a uniform degree of accuracy of measurement throughout the country. This would reduce expenditure at favourable sites (where the largest possible structure would be too small or where flow conditions become unsuitable at higher stages).

Frere's conclusion suggested that standard Design Capacity to measure 50% total runoff be adopted and be given by the expression:-

$$P = 0.02A \text{ Cumecs}$$

where A is the catchment area in km^2.

GROUNDWATER - THE PAST

From the human point of view, economically accessible groundwater of depths of less than say 100 metres forms the largest single source of water supply in Zimbabwe. In much of the arid and semi-arid regions of Zimbabwe, groundwater is the only source of supply. Paradoxically, despite its great importance from both the physical and human view-points, groundwater has, until recently, appeared to be one of the neglected fields of hydrology; here, more than anywhere, the maxim "Out of sight - out of mind" has been applicable. In Zimbabwe this has certainly been the case.

Despite the fact that in the past fifty years approximately 30 000 boreholes have been drilled in this country, we know relatively little about this vital resource. One possible reason for this situation is that 99% of these boreholes were drilled primarily for domestic purposes, both by the Government, Water Development Provincial Sections and private enterprise drilling firms on an *ad hoc* basis as and when they were required. As a result the records available of the relevant data for each borehole, e.g. depth of first supply, rock type, yield, etc. are to a certain extent suspect and not as rigorous as one would like, and for half the boreholes no records are available. This situation was rectified with the promulgation of the Water Act (1976) which requires every owner of a newly drilled borehole to supply the Ministry of Water Development with their records. The first collation and analysis of borehole records were carried out by Lange in 1954, to be followed by Hindson and Dennis (1962) (Groundwater Provinces of Southern Rhodesia), Hindson (1962), and then Gear (1976) and finally the current computerization program by the Hydrological Branch of the Ministry of Natural Resources and Water Development of all boreholes drilled in Zimbabwe. However, as noted earlier, some of the input data has had to be inferred and is of mediocre quality. Nonetheless, a first order approximation of mean yields and depths in differing rock types began to emerge. But perhaps of even greater import is the gap in groundwater data in Zimbabwe *viz.* the virtual absence of long-term water table measurements. Again, this too can be ascribed to the fact that it is only recently that groundwater situated in the crystalline rocks has been considered in terms other than just a small domestic drinking supply. It was only in 1979 that the Branch began to consider that boreholes of moderate yield in the crystalline rocks could and should be used for small-scale plot irrigation in the rural areas.

The first rigorous groundwater research program to prove the existence of large groundwater basins capable of sustaining yields suitable for large-scale irrigation projects commenced in 1958 with the Sabi (now Save) Valley study, closely followed by a research program of the potential of the Nyamandhlovu aquifer and several relatively small isolated alluvial deposits in the southern half of Zimbabwe. All these projects were carried out in sedimentary deposits where there was little need for geophysical measurements. Test boreholes were drilled and classical groundwater analysis techniques reinforced by radio-isotope studies were used to obtain aquifer characteristics. Large groundwater supplies were obtained, but it must be recalled that these areas were exceptionally favourable for groundwater development.

Despite the fact that water divining had a strong following in Zimbabwe, geophysical techniques for groundwater location were first used in 1934. The method of choice in Zimbabwe has been the electrical resistivity technique and 75% of all Government drilled boreholes were sited by this means.

However, the author strongly believes that the role of geophysics in groundwater exploration in Zimbabwe does require re-assessment. In the new program of shallow groundwater exploitation it appears that the resistivity method has minimal prediction value in delineating the regolith. The Seismic Technique has been attempted but the results are dubious. Experience, surface geology and topography may well prove more cost beneficial.

Nuclear techniques in groundwater hydrology were first attempted in 1964. Two types of tracer were used to obtain groundwater flow rates. Firstly, environmental tritium allowed the dating of groundwater and secondly, the injection of artificial gamma emitting radio tracers into a borehole to give the point dilution method which allows flow velocity to be determined using a single borehole.

The low level tritium counting facility built by Ward and Wurzel in 1964 was only the third such facility in the southern hemisphere. The primary groundwater nuclear research program centred on the Save Valley alluvial plain (the largest tract of alluvium in Zimbabwe) but several other programs followed. The range of work carried out can be seen from the titles of the papers published by Ward and Wurzel (1965; 1968a; b; c; d), Wurzel and Ward (1968; 1969) and Wurzel (1971b; 1972; 1974; 1981; 1984). Pre-eminent in the Save Valley investigation was L.L. Hindson, for many years Chief Geogphysical Officer of the Hydrological Branch. In addition to the isotope work by Ward and Wurzel, an isotope input was recently provided by Prof. B. Verhagen of the University of the Witwatersrand Nuclear Physics Research Unit. Prof. Verhagen spent two weeks in Zimbabwe in a study of the Umboe groundwater reservoir collecting water samples for carbon 14, tritium and stable isotope analysis. Preliminary results indicate a series of discrete groundwater basins in the Lomagundi Dolomites. Verhagen is also involved in a countrywide stable isotope analysis of both surface and groundwater.

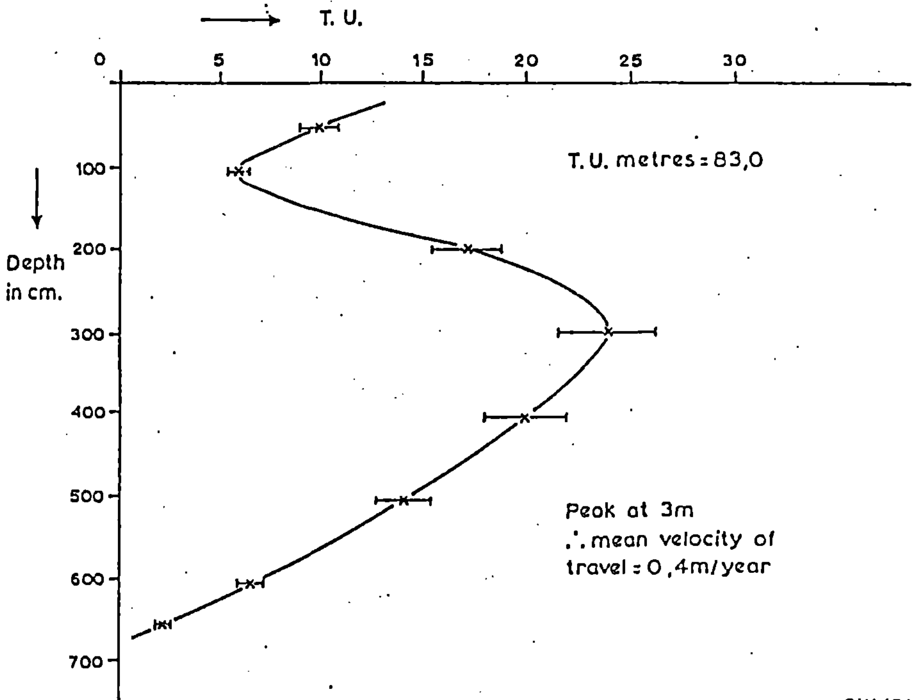
A stable isotope study of 13 catchments on crystalline rocks in all parts of the country is being funded by UK Geological Survey and is a joint research project with the Ministry and Verhagen towards a better understanding of shallow groundwater in the crystalline rocks.

While 99% of all boreholes drilled in Zimbabwe were drilled by percussion rigs, the acquisition by the Hydrological Branch, in 1972, of a reverse circulation drill rig and several air rotary rigs allowed more rapid, more controlled and deeper drilling. Considerable research was carried out on the efficacy of different gravel packs in the large diameter reverse circulation holes, the existence of vertical currents in the gravel packs, etc. etc.

For an unexplained reason there exists very little data on groundwater quality in Zimbabwe. It is true that poor quality water soon manifests itself but a wide range of water quality is tolerable both to humans and agriculture and it is vital that data be available. In only two areas has a generalised water quality picture emerged. In north-east Matabeleland a high fluoride water basin has been identified and in the Binga area on the shores of Lake Kariba a high magnesium bicarbonate water exists which has a particularly debilitating effect on the children of the area who suffer from chronic diarrhoea. Currently aid funds are being sought to allow the Ministry to set up a water quality laboratory.

As a result of the lack of systematic groundwater level data, little is known of recharge rates into the different groundwater basins. The tritium profiling method of tracing the movement of the 1963 northern hemisphere thermonuclear peak as it makes its way through the soil has provided an elegant and unique technique to estimate recharges. This work is being carried out by the Hydrological Branch, and a typical profile in granitic soil is shown in Figure 6. However, many profiles are required before a recharge rate for the various soil types is available.

FIGURE 6: TRITIUM PROFILE IN GRANITIC SOIL 1970



PW/RM

SURFACE WATER - THE FUTURE

Currently there are 350 weirs and recorder stations in Zimbabwe plus 500 gauge plate stations. This already comprehensive network will be expanded, thus allowing for update assessment of water availability and the effects of new water right applications on existing rights.

The computer will obviously be central to all data collection and storage. A data base for both the flow records and water rights which is accessible to various retrieval programs for data extracting and manipulation is planned.

Comparative sediment surveys in the major dams are of high priority. The "wet lands" (vleis or dambos) of Zimbabwe are presently being investigated by the Universities of Southampton and Loughborough with a significant local input. The role of vleis in the disposition of surface water has not been fully established and is of considerable agricultural import; a better understanding of the hydrology of vleis will emerge as a result of these studies.

Much attention has currently focussed on remote sensing techniques in hydrology. These techniques are actively being pursued in Zimbabwe with UN aid.

GROUNDWATER - THE FUTURE

This is the resource of the future; particularly in the rural areas.

A national rural water supply master plan is about to be presented to the Government by Norwegian donor aid, following a three year, two million dollar study. Many of the recommendations in this plan require evaluation and confirmation. In the past, groundwater in the crystalline rocks in Zimbabwe (which form 66% of the surface outcrop) was sought in the semi-decomposed zone, relatively deep (>30 m). The new philosophy of shallow groundwater exploitation both by specially constructed boreholes and wells remains to be shown viable. The large diameter well programme (5 m diameter and therefore much storage) is currently also being evaluated. The efficacy of drilling collector tubes in these large wells has been proven, but the cost/benefit ratio of these large wells remains in question.

CONCLUSION

Although Zimbabwe is a Third World developing country, this paper amply demonstrates its high degree of water resource development which is closely allied to commitment and work of the past and forward planning made possible by 50 years of data collected and researched by the Hydrological Branch of the Ministry of Water Resources and Development. Hydrology in Zimbabwe reached its zenith when the International Association of Scientific Hydrology decided to hold its first International Conference in Africa in Harare, Zimbabwe. The honour was duly repaid and the importance attached to hydrology duly emphasised when the Prime Minister of Zimbabwe opened the Conference. Many eminent international hydrologists came to Zimbabwe to discuss two major topics: groundwater and soil erosion and in both realms Zimbabwe hydrologists contributed significantly.

Dramatic strides are currently being made in Zimbabwe hydrology and water resources development - with a burgeoning and rapidly expanding population, such strides have to be dramatic to ensure the Government's attempt to provide safe drinking water for all by the year 2000.

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